REMARKS

Pending in the present application are claims 1-55. Claims 1-27 are rejected under 35 USC 112, first paragraph, as failing to comply with the written description requirement. Claims 1-55 are rejected under 102(e) as being anticipated by Cessna et al (USP 6,510,420). The rejections are respectfully traversed without amendment of the claims.

Preliminary Statement Regarding Simulation

The premise of this rejection is that Cessna does not have to teach simulation technology to support a Section 102(e) rejection, either because simulation is new matter or because simulation and projection are synonymous. This view misapprehends the nature of simulation and misses much of the teaching in this application.

It is useful to have in mind that applying the broadest reasonable interpretation of "simulating" is not purely a matter of Examiner's discretion, as "[t]he broadest reasonable interpretation of the claims must also be consistent with the interpretation that those skilled in the art would reach" in light of the specification. MPEP, § 2111, at 2100-46 to -47 (Rev. 2, May 2004) (citing *In re Cortright*, 165 F.3d 1353, 1359 (Fed. Cir. 1999), in which the Federal Circuit reversed the Board's construction of a claim limitation based on applicant's disclosure and other published examples of usage). It is important to tie the meaning of simulation to how the term is used by those of skill in the art and how it would be understood in the art in light of the specification.

Simulation is described in the attached papers by employees of Cessna assignee IBM and by principals of NovaSim, LLC. These papers describe inventory management simulation as including modeling of inventory flow and tracking discrete events using simulators. Lin et al., "*Extended-Enterprise Supply-Chain Management at IBM Personal Systems Group and Other Divisions*", Interfaces 30:1, pp. 7-25, at pp. 12-13 (Jan.-Feb. 2000) available at http://www.interfaces.smeal.psu.edu/pdf/v30n1a2.pdf; Hauge et al., "*How Low Can You Go? Using Simulation to Determine Appropriate Inventory Levels*", attributed to IIE Lean Management Solutions, September 23-24, 2002, Seattle, WA, (publication data unverified)

http://www.novasim.com/downloads/How%20Low%20Can%20You%20Go.pdf, accessed 10 January 2005. *See, also*, NovaSim, "*What is Simulation?*" http://novasim.com/services/sim_ed/whatissim.html, accessed 18 January 2005.. Simulation is a tool of industrial engineering and operations research that is available for academic study of inventory management, which this application substantially extends to real-world retail distribution and sales.

Simulation is described throughout this application, including paragraphs [0328-0332] and [0336-0338], and in text that the Examiner quotes on page 10 of the Office Action. Notional orders to simulate future stocking patterns for reorderable items is a good example of simulation technology described in the application, which the Examiner has acknowledged. *Id.* A notional order is a simulated order (*see, e.g.*, [0059], [0328], [0336]), which this application explains can only be placed in the future ([0066]), because it makes no sense to simulate something as having happened in the past that we know did not happen. From the point at which a simulated notional order is placed, one can simulate fulfillment of that order to the point that goods become available to sell and are sold in a store. This simulation places short lead time items on equal footing with long lead time items for analytical purposes. This simulation, which NovaSim calls "discrete event simulation", has more meaning than most people ascribe to "projection". One of skill in the art will recognize that simulation is described by this application.

Applicants have consulted leading technical dictionaries to see if the dictionaries use simulation and projection as synonyms. There was no similarity between the definitions of these words in either *McGraw-Hill Dictionary of Scientific and Technical Terms*, at 1587-88 & 1831 (Fifth Ed. 1994) or *Academic Press Dictionary of Science and Technology*, at 1734 & 1994 (1992). We do not understand what evidentiary basis the Examiner has for treating them as synonyms.

Discrete event simulation is not synonymous with either projection or what Cessna teaches. Simulation, in an operations research or inventory management sense, implies an underlying model of how causal events are linked and stepwise tracking of events that impact the model. Simulation is a process. Projection has a looser meaning, as we all can "project" what will happen in our own life or even world events without any study, model or stepwise tracking of events. While simulations may

produce projections, having a projection does not imply that a simulation was run to produce it.

Simulation is not discussed in or synonymous with teachings of IBM's Cessna patent. Compare, for instance, how simulation is described by IBM on pages 12-13 of the attached article. Lin et al., *"Extended-Enterprise Supply-Chain Management at IBM Personal Systems Group and Other Divisions"*, Interfaces 30:1, pp. 7-25, at pp. 12-13 (Jan.-Feb. 2000). OLAP in Cessna and simulation in Lin are not the same technology. Cessna clustering for OLAP says nothing about simulation.

With this distinction between simulation and Cessna in mind, the Examiner's arguments responding to explanations given by Applicants can readily be rebutted.

<u>Claim Rejections under 35 USC 112</u>

Claims 1-27 are rejected under 35 USC 112, first paragraph, as failing to comply with the written description requirement. Applicants recognize that it would have been better to give page and line references in the last response that show where the amended terms can be found. We now supply that information.

The now claimed limitation, "simulating unit inventory and unit sales on a bottom-up per location basis", is depicted in FIG. 45 and described in [0328-0332]. From [0328], "One approach to executing the new OTB methodology is to run a simulation for individual items and locations, simulating projected sales and other factors impacting inventory levels. Simulated results are rolled up to arrive at a higher level of the product hierarchy..." One of skill in the art will understand that rolling up from individual items and locations is "bottom up" simulation.

The now claimed limitation, "wherein notional deliveries result from projected orders that have not yet been submitted to suppliers when simulating unit inventory and unit sales", is described in [0066], [0336] and [0338]. For instance, from [0336], "Determine additional notional orders that will need to be placed in the future, including the expected quantity and receipt date for those orders to put all items on an equal footing. Notional orders and deliveries or receipts refer to system projected orders and resulting deliveries that have not been submitted to suppliers."

With the amended limitations firmly tied to the text of this lengthy application, Applicants respectfully request that the Section 112 rejections be withdrawn.

Claim Rejections Under 35 USC 102

Claims 1-55 are rejected under 102(e) as being anticipated by Cessna et al (USP 6,510,420). As we go through the rejections, we are mindful both of the rejections beginning at page 4 of the Office action and the responses beginning at page 10. Our replies are organized with the same granularity as the rejections.

The Examiner rejects **claim 1** in the Office Action at p. 4, citing the same figures and passages from Cessna as before, with the additional "Examiner's Note (EN): the purpose of the model is a merchandise planning system with a structure objects ... data ... system ... algorithm which will derive dollar inventory and dollar sales as a step in clustering similar characteristics; new matter applies to the 'simulating' clause.)"

Applicants take the EN regarding new matter and simulating as a concession that Cessna does not describe simulation, in an operations research / inventory control sense of simulation. So the rejection should be withdrawn if simulation is described in the application. Variations of the word "simulate" are used at least ten times in the application. The claim 1 language is tied to and described in [0328-0332], as explained above. The written description / new matter issue having been resolved, the rejection effectively concedes that Cessna does not anticipate "simulating" in an operations research / inventory control sense.

The Examiner responds regarding claim 1 at p. 10, by arguing that "'simulating' does not have a special definition set forth by the applicant in the specification." Applicants have used simulation in the same manner as one of ordinary skill in the art with training in operations research / inventory management. The ordinary use of the term "simulating" in this art is shown in the attached papers and by the context in which it is used in the specification. The term "simulating" is not synonymous, to one of skill in the art, with any technology expressly described by Cessna.

Applicants respectfully submit that claim 1 should be allowable over Cessna.

The Examiner rejects **claim 2** in the Office Action at p. 4, citing the same passages from Cessna as before. The Examiner responds regarding claim 2 at p. 10-11, by arguing that the three words "merchandise planning system" used at col. 3, lines

45 et seq. to identify one of several environments in which OLAP clustering technology can be applied, "does indeed cover the applicant's generic aspects of gross margins, inventory costs and projected costs related to operations of deliveries." OA, p. 4. If the Examiner is prepared to offer his own declaration as evidence of this conclusion, then Applicants would like to see the declaration. Contrary to the Examiner's argument, while Cessna discusses a merchandise planning system at columns 3-12, Applicants cannot find any teaching, description or even mention what the Examiner considers to be implied. MPEP 212 at 2100-54 to –55 (Rev. 2, May 2004) sets forth a strict rule for implying features into Cessna,

> "In relying upon the theory of inherency, the examiner must provide a basis in fact and/or technical reasoning to reasonably support the determination that the allegedly inherent characteristic necessarily flows from the teachings of the applied prior art." *Ex parte Levy*, 17 USPQ2d 1461, 1464 (Bd. Pat. App. & Inter. 1990) (emphasis in original).

Applicants suggest that OLAP clustering can be applied to any body of data, without necessity that the particular quantities of projected unit inventory, unit sales, dollar inventory or dollar sales from the items be calculated on a per-item basis or be rolled up. An OLAP clustering technology could be applied to groups of items in a store as readily as single items, so the "necessarily flows" test is not met.

Applicants expressly deny purportedly admitting Cessna's application to claim 2, for reasons explained above.

Applicants respectfully submit that claim 2 should be allowable over Cessna.

The Examiner rejects **claim 3** in the Office Action at p. 5, citing the same passages from Cessna as before. The Examiner responds regarding claim 3 at pp. 10-11, by grouping claims 2-4. Applicants have traversed the claim 2 response above, at length, and apply that rebuttal to claim 3 as well.

Applicants respectfully submit that claim 3 should be allowable over Cessna.

The Examiner rejects **claim 4** in the Office Action at p. 5, citing the same passages from Cessna as before. The Examiner responds regarding claim 4 at pp. 10-11, by grouping claims 2-4. Applicants have traversed the claim 2 response above, at length, and apply that rebuttal to claim 4 as well.

Applicants respectfully submit that claim 4 should be allowable over Cessna.

The Examiner rejects **claims 5-6** in the Office Action at p. 5, citing the same passage from Cessna as before, with the additional EN "new matter applies to the 'wherein' clause." Applicants take the EN regarding new matter as a concession that Cessna does not describe the limitation in the wherein clause. So the rejection should be withdrawn if the wherein clause is described in the application. The wherein clause is tied, above, to and described in [0066], [0336] and [0338]. For instance, from [0336], "Determine additional notional orders that will need to be placed in the future, including the expected quantity and receipt date for those orders to put all items on an equal footing. Notional orders and deliveries or receipts refer to system projected orders and resulting deliveries that have not been submitted to suppliers." The written description / new matter issue having been resolved, the rejection effectively concedes that Cessna does not anticipate the limitation of the wherein clause.

The Examiner responds regarding claims 5-6 at p. 11, with several arguments. First, the Examiner reargues Section 112, which argument is answered in the preceding paragraph. Second the Examiner argues that notional deliveries "would be included" in programs referred to by Cessna at col. 1, lines 25-32. The Examiner's words reveal that he really is making a Section 103 rejection, not a Section 102(e) rejection, because he relies on the supposed capabilities of programs that Cessna names but does not describe as the basis of the rejection. Until the Examiner provides evidence of what "would be included" in the unidentified references, Applicants cannot fairly respond. Third, the Examiner argues that "simulating is merely a generic projection", to which Applicants responded above.

Applicants respectfully submit that claims 5-6 should be allowable over Cessna.

The Examiner rejects **claims 7-12** in the Office Action at p. 5, citing the same passage from Cessna as before. The Examiner responds regarding claims 7-12 at p. 12, by incorporating by reference unspecified "above remarks". Applicants have responded point by point to anything that could be construed as "above remarks".

Simulated "notional deliveries", as described in the specification, are not described in Cessna.

Applicants respectfully submit that claims 7-12 should be allowable over Cessna.

The Examiner rejects **claims 13-15** in the Office Action at p. 6, citing the same passages from Cessna as before, with the additional EN "simulating and projecting are synonymous", to which Applicants replied above. The Examiner responds regarding claims 13-15 at p. 12, by invoking his synonym argument and arguing that unit sales, periods, causal events and promotions are part of the method described by Cessna at col. 2, lines 19-59. For ease of reference, the cited passage is reproduced below:

> The present invention addresses the above-mentioned problems by providing a system and method for dynamically building hierarchical groupings of business information based on multidimensional member characteristics. The system includes a computer program that comprises: (1) a mechanism for choosing one or more characteristic orders (i.e., a hierarchical model), a characteristic set made up of N characteristics, and an initial set of members; (2) a mechanism for assigning characteristic values for each of the N characteristics for each of the initial set of members; (3) a mechanism for dynamically creating hierarchical levels and level to level relationships based on the chosen characteristic order(s); and (4) a mechanism for dynamically creating new members and member to member relationships in each of the hierarchical levels.
>
> Within the system, each of the level to level relationships includes a parent level and a child level, wherein the child level includes M characteristics and the parent level includes a subset of the M characteristics. New members can be created in the parent level by grouping (or clustering) together members in the child level that share the same characteristic values for each of the subset of the M characteristics. The clustering process is facilitated by having a consistent naming convention for both members and levels.
>
> Accordingly, to create a first level of members based on the set of initial members, the system comprises a mechanism for grouping together initial members and their characteristic values into distinct clusters, such that each distinct cluster comprises a set of initial members having the same N characteristic values. Each distinct cluster then becomes a first level member.
>
> The method comprises the steps of: (1) choosing a characteristic order, a characteristic set made up of N characteristics, and an initial set of members; (2) assigning characteristic values for each of the N characteristics for each of the initial set of members; (3) dynamically creating hierarchical levels and level to level relationships based on the chosen characteristic order; and (4) dynamically creating new members and member to member relationships in each of the hierarchical levels.

Applicants cannot find in this cited passage any of the claimed specifics to which the Examiner would apply Cessna's abstract framework. No particular underlying data is

<u>necessarily</u> implied by the abstract framework, as required for a rejection on inherency grounds.

Therefore, Applicants respectfully submit that claims 13-15 should be allowable over Cessna.

The Examiner rejects **claim 16** in the Office Action at p. 6, citing the same col. 2, lines 51-59 passage from Cessna as before. The Examiner responds regarding claim 16 at p. 12, by invoking his synonym argument and arguing that "Cessna @ claims 10-20 identif[ies] a planning program wherein the generic characteristics ***would include*** unit sales over periods of time." Claims 10 and 16 are the independent claims, both of which describe a generic hierarchical model or grouping as part of a "planning" program or system. The Examiner's words reveal that he really is making a Section 103 rejection, not a Section 102(e) rejection, because he relies on the supposed capabilities of programs that Cessna names but does not describe as the basis of the rejection. Until the Examiner provides evidence of what "would be included" in the unidentified references, Applicants cannot fairly respond. The absence of features that the Examiner says would be included in another reference makes it clear that Cessna does not, by itself in a single reference, anticipate the claim.

Applicants respectfully submit that claim 16 should be allowable over Cessna.

The Examiner rejects **claim 17** in the Office Action at p. 6, citing the same passages from Cessna as before, which do not mention stockouts. The Examiner responds regarding claim 17 at pp. 12-13, grouping it with the claim 16 response, to which Applicants replied above.

The Examiner's response on p. 13 is unresponsive. Applicants previously asserted the failure of Cessna to model by simulation stockouts, in and out dates for items, last purchase order receipt dates, or causal events, or even to mention the features of retailing. Invoking the synonym argument is unresponsive. The previously cited passages do not mention stockouts, and repeating citation of col. 6, lines 39-59 cannot change the fact that stockouts are not mentioned in the cited passage.

Applicants respectfully submit that claim 17 should be allowable over Cessna.

The Examiner rejects **claim 18** in the Office Action at p. 6, citing the same passages from Cessna as before, which do not mention in dates or out dates. The Examiner responds regarding claim 18 at pp. 12-13, grouping it with the claim 17 response, to which Applicants replied above. Neither in dates nor out dates are mentioned in the cited passage at col. 6, lines 39-59.

Applicants respectfully submit that claim 18 should be allowable over Cessna.

The Examiner rejects **claims 19-20** in the Office Action at p. 6, citing the same passages from Cessna as before, which do not mention out dates in the alternative senses defined by these dependent claims. The Examiner responds regarding claims 19-20 at pp. 12-13, grouping it with the claim 17 response, to which Applicants replied above. Out dates in the alternative senses defined by these dependent claims are not mentioned in the cited passage at col. 6, lines 39-59.

Applicants respectfully submit that claims 19-20 should be allowable over Cessna.

The Examiner rejects **claim 21** in the Office Action at p. 6, citing the same passages from Cessna as before, which do not mention in dates or out dates. The Examiner responds regarding claim 21 at pp. 12-13, grouping it with the claim 17 response, to which Applicants replied above. Neither a plurality of in dates nor a plurality of out dates are mentioned in the cited passage at col. 6, lines 39-59.

Applicants respectfully submit that claim 21 should be allowable over Cessna.

The Examiner rejects **claim 22** in the Office Action at p. 7, citing the same passages from Cessna as before, which do not mention last purchase order receipt dates. The Examiner responds regarding claim 22 at pp. 12-13, grouping it with the claim 17 response, to which Applicants replied above. Last purchase order receipt dates are not mentioned in the cited passage at col. 6, lines 39-59.

Applicants respectfully submit that claim 22 should be allowable over Cessna.

The Examiner rejects **claim 23** in the Office Action at p. 7, citing the same passages from Cessna as before, which do not mention last purchase order receipt dates for a plurality of locations. The Examiner responds regarding claim 22 at pp. 12-13, grouping it with the claim 23 response, to which Applicants replied above. Last purchase order receipt dates for a plurality of locations are not mentioned in the cited passage at col. 6, lines 39-59.

Applicants respectfully submit that claim 23 should be allowable over Cessna.

The Examiner rejects **claim 24** in the Office Action at p. 7, citing the same passages from Cessna as before, which do not mention causal events as that term is used in this specification. The Examiner responds regarding claim 24 at pp. 12-13, grouping it with the claim 17 response, to which Applicants replied above. Causal events, as that term is used in this specification, are not mentioned in the cited passage at col. 6, lines 39-59.

Applicants respectfully submit that claim 24 should be allowable over Cessna.

The Examiner rejects **claims 25-27** in the Office Action at p. 7, citing the same passages from Cessna as before, which do not mention causal events as that term is refined in these dependent claims. The Examiner responds regarding claims 25-27 at pp. 12-13, grouping it with the claim 17 response, to which Applicants replied above. Causal events, as that term is refined in these dependent claims, are not mentioned in the cited passage at col. 6, lines 39-59.

Applicants respectfully submit that claims 25-27 should be allowable over Cessna.

The Examiner rejects **claim 28** in the Office Action at pp. 7-8, citing the same passages from Cessna as before. The Examiner responds regarding claim 28 at p. 13, beginning with a question:

> [1] If "notional deliveries" is defined in specification @ p 0336, but yet has another definition in the independent claim 28, what is the definition of "notional deliveries"? At best the specification and the claims are at attempting to define something that really has not been defined clearly. [2]

> Comments of claim 1 apply. [3] Applicant admits that the appropriate concepts are resident in the prior art of Cessna. [4] Concise and clear statements of concepts are all that is required for prior art to anticipate the applicant's invention.

Reading the specification, it is already clear that notional deliveries result from notional orders that are set for dates after the simulation run date, as explained above. Future notional orders are distinct from outstanding orders, which necessarily are past orders as of the simulation run date. There is no lack of clarity in Applicants' submission.

Regarding [2], the Examiner's words are another way of invoking the synonym argument, to which Applicants responded above.

Regarding [3], Applicants admit nothing of the sort. The appropriate concepts are not resident in Cessna, as twice explained in great detail.

Regarding [4], the Examiner is reminded that the standard for proof of anticipation is not "concise and clear statements of concepts", whatever that means, but, as set out in MPEP 2131, at 2100-73,

> TO ANTICIPATE A CLAIM, THE REFERENCE MUST TEACH EVERY ELEMENT OF THE CLAIM
>
> "A claim is anticipated only if each and every element as set forth in the claim is found, either expressly or inherently described, in a single prior art reference." *Verdegaal Bros. v. Union Oil Co. of California*, 814 F.2d 628, 631, 2 USPQ2d 1051, 1053 (Fed. Cir. 1987). >"When a claim covers several structures or compositions, either generically or as alternatives, the claim is deemed anticipated if any of the structures or compositions within the scope of the claim is known in the prior art." *Brown v. 3M*, 265 F.3d 1349, 1351, 60 USPQ2d 1375, 1376 (Fed. Cir. 2001) (claim to a system for setting a computer clock to an offset time to address the Year 2000 (Y2K) problem, applicable to records with year date data in "at least one of two-digit, three-digit, or four-digit" representations, was held anticipated by a system that offsets year dates in only two-digit formats). See also MPEP § 2131.02.< "The identical invention must be shown in as complete detail as is contained in the ... claim." *Richardson v. Suzuki Motor Co.*, 868 F.2d 1226, 1236, 9 USPQ2d 1913, 1920 (Fed. Cir. 1989). The elements must be arranged as required by the claim, but this is not an *ipsissimis verbis* test, i.e., identity of terminology is not required. *In re Bond*, 910 F.2d 831, 15 USPQ2d 1566 (Fed. Cir. 1990).

We note that the level of detail at which anticipation of every element of the claim was tested in *Brown v. 3M*, as described in the MPEP, is whether year date was expressed in two, three or four digits. Depending on what the Examiner means by concise and

clear statements of concepts, the Examiner's notion may not meet the requirements of the every element rule.

The Applicants respectfully submit that claim 28 should be allowable over Cessna.

The Examiner rejects **claim 29** in the Office Action at p. 8, citing the same passages from Cessna as before. The Examiner responds regarding claim 29 at p. 14, by arguing that the wherein clause is new matter. Applicants take this new matter argument as a concession that Cessna does not describe the limitation in the wherein clause. So the rejection should be withdrawn if the wherein clause is described in the application. The wherein clause is tied, above, to and described in [0066], [0336] and [0338]. For instance, from [0336], "Determine additional notional orders that will need to be placed in the future, including the expected quantity and receipt date for those orders to put all items on an equal footing. Notional orders and deliveries or receipts refer to system projected orders and resulting deliveries that have not been submitted to suppliers." The written description / new matter issue having been resolved, the rejection effectively concedes that Cessna does not anticipate the limitation of the wherein clause.

The Examiner further argues on p. 14 that, "Cessna planning applications embodies a multidimensional analysis for the planning of the future of a business (Cessna @ c 6, 1 39-49)." Whether or not the Examiner is right, this statement cannot meet the every element rule and cannot justify an anticipation rejection.

Applicants respectfully submit that claim 29 should be allowable over Cessna.

The Examiner rejects **claim 29** in the Office Action at p. 8, citing the same passages from Cessna as before. The Examiner responds regarding claim 29 at p. 14, grouping it with the claim 28 response, to which Applicants replied above.

Applicants respectfully submit that claim 29 should be allowable over Cessna.

The Examiner rejects **claims 30-31** in the Office Action at p. 8, citing the same passages from Cessna as before. The Examiner responds regarding claims 30-31 at

p. 14, grouping it with the claim 28 response, to which Applicants replied above.

Applicants respectfully submit that claims 30-31 should be allowable over Cessna.

The Examiner rejects **claim 32** in the Office Action at p. 8, citing the same passages from Cessna as before. The cited passages, Cessna, col. 2, lines 51-59 and col. 5, lines 31-40, are an empty shell that does not describe or enable simulating of unit sales for daily or more frequent periods or on a location-by-location basis.

The Examiner's response on p. 14 is unresponsive. Applicants previously asserted the failure of Cessna to teach or even mention simulating unit sales for daily or more frequent periods or on a location-by-location basis. Invoking the synonym argument is unresponsive. The previously cited passages do not mention simulation, much less simulating unit sales for daily or more frequent periods or on a location-by-location basis. Repeating citation of col. 6, lines 39-59 cannot change the fact that simulating unit sales for daily or more frequent periods or on a location-by-location basis is not mentioned in the cited passage.

Applicants respectfully submit that claim 32 should be allowable over Cessna.

The Examiner rejects **claims 33-37** in the Office Action at p. 8, citing the same passages from Cessna as before. The Examiner responds regarding claims 33-37 at p. 14, grouping them with the claim 32 response, to which Applicants replied above.

Applicants respectfully submit that claims 33-37 should be allowable over Cessna.

The Examiner rejects **claims 38-41** in the Office Action at p. 8, citing the same passages from Cessna as before. These claims refine "notional deliveries", as that term is used in claims 28-29. The Examiner responds regarding claims 38-41 at p. 14, "The above comments and First Office Action applies." Applicants are unsure what "above comments" the Examiner intends to invoke, but feels confident that the above replies are responsive. Reference to the first Office Action is unresponsive. "These claims further limit application of notional deliveries. The lack of these further limitations

on notional deliveries (or notional deliveries, at all) in Cessna is an additional basis for claims 38-49 being allowable over Cessna."

Applicants respectfully submit that claims 38-41 should be allowable over Cessna.

The Examiner rejects **claims 42-43** in the Office Action at p. 9, citing the same passages from Cessna as before. The Examiner responds regarding claims 42-43 at p. 14, grouping them with the claims 38-41 response, to which Applicants replied above.

Applicants respectfully submit that claims 42-43 should be allowable over Cessna.

The Examiner rejects **claims 44-45** in the Office Action at p. 9, citing the same passages from Cessna as before. The Examiner responds regarding claims 44-45 at p. 14, grouping them with the claims 38-41 response, to which Applicants replied above.

Applicants respectfully submit that claims 44-45 should be allowable over Cessna.

The Examiner rejects **claims 46-47** in the Office Action at p. 9, citing the same passages from Cessna as before. The Examiner responds regarding claims 46-47 at p. 14, grouping them with the claims 38-41 response, to which Applicants replied above.

Applicants respectfully submit that claims 46-47 should be allowable over Cessna.

The Examiner rejects **claims 48-49** in the Office Action at p. 9, citing the same passages from Cessna as before. The Examiner responds regarding claims 48-49 at p. 14, grouping them with the claims 38-41 response, to which Applicants replied above.

Applicants respectfully submit that claims 48-49 should be allowable over Cessna.

The Examiner rejects **claims 50-51** in the Office Action at p. 9, citing the same passages from Cessna as before. The Examiner responds regarding claims 50-51 at pp. 14-15, by arguing that "[p]rorating is part of dimensional modeling described by Cessna @ c5, l 31-40." For ease of reference, the cited passage is reproduced below:

> Dimensional modeling entails maintaining business information (e.g., sales) and dimensional structures (e.g., product, location, time) for viewing business information. Business information is numerical measurements of the business data. Dimensions are independent, business specific abstractions that provide a mechanism for partitioning and subsequently viewing business information. Such information resides in a hierarchical manner within a dimension. The hierarchical views allow a user to view facts at an arbitrary, but predetermined granularity.

Applicants cannot find in this cited passage any mention of prorating, to which the Examiner would apply Cessna's abstract framework. Prorating, as claimed, is not <u>necessarily</u> implied by the abstract framework, as required for a rejection on inherency grounds.

Applicants respectfully submit that claims 50-51 should be allowable over Cessna.

The Examiner rejects **claims 52-55** in the Office Action at pp. 9-10, citing the same passages from Cessna as before. The claimed "recapture of projected lost sales" common to these claims is part of generating data, which Cessna's abstract manipulation framework might manipulate. But Cessna does not teach this sophisticated simulation technique, or any other simulation at all.

The Examiner responds regarding claims 52-55 at pp. 15-16, by arguing that, "Cessna is a sophisticated framework for dynamic hierarchical grouping and calculation based on multidimensional member characteristics as evidenced by Cessna's Section 2 entitled "Overview of Dimensional Modeling which ***would include*** stockout considerations related to its appropriate level in the model hierarchy." The Examiner's words reveal that he really is making a Section 103 rejection, not a Section 102(e) rejection, because he relies on the supposed capabilities of programs that generate data which Cessna would manipulate. Until the Examiner provides evidence of what

the unidentified references "would include", Applicants cannot fairly respond. The absence of features that the Examiner says would be included in another reference makes it clear that Cessna does not, by itself in a single reference, anticipate the claims.

Applicants respectfully submit that claims 52-55 should be allowable over Cessna.

Regarding general principle, the Examiner says, "Applicant is reminded that the mere date of the publication may not necessarily disqualify the document as prior art." The Examiner must be thinking of MPEP 2124, which allows use of a disqualified reference for purposes other than as a prior art reference. This is like using evidence in court for one purpose but not another. Since the reference involved is a Japanese publication, the Examiner is directed to MPEP 2128.02, as to the date on which the publication is available as a reference.

CONCLUSION

Applicants respectfully submit that the claims, as stated herein, are in condition for allowance and solicit acceptance of the claims, in light of these remarks. If the Examiner disagrees and sees amendments that might facilitate allowance of the claims, a call to the undersigned would be appreciated.

If a telephone conference would assist in resolving any issues, the undersigned can normally be reached at (650) 712-0340, Monday through Friday, from 8:30 AM through 5:30 PM, excepting lunch.

Respectfully submitted,

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Dated: 05 April 2005

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In 1994, IBM began to reengineer its global supply chain. It wanted to achieve quick responsiveness to customers with minimal inventory. To support this effort, we developed an extended-enterprise supply-chain analysis tool, the Asset Management Tool (AMT). AMT integrates graphical process modeling, analytical performance optimization, simulation, activity-based costing, and enterprise database connectivity into a system that allows quantitative analysis of extended supply chains. IBM has used AMT to study such issues as inventory budgets, turnover objectives, customer-service targets, and new-product introductions. We have implemented it at a number of IBM business units and their channel partners. AMT benefits include over $750 million in material costs and price-protection expenses saved in 1998.

As the world's largest company providing computer hardware, software, and services, IBM makes a wide variety of products, including semiconductors, processors, hard disks, personal computers, printers, workstations, and mainframes. Its manufacturing sites are linked with tens of thousands of suppliers and distribution channels all over the world. A single product line may involve thousands of part numbers with multilevel bills of materials, highly varied lead times and costs, and dozens to hundreds of manufacturing and distribution sites

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linked by different transportation modes. Facing the challenges of increasing competition, rapid technology advance, and continued price deflation, the company launched an internal reengineering effort in 1993 to streamline business processes in order to improve the flow of material and information. The reengineering effort focused on improving customer satisfaction and market competitiveness by increasing the speed, reliability, and efficiency with which IBM delivers products to the marketplace.

In 1994, IBM launched an asset-management reengineering initiative as part of the overall reengineering effort. The objectives were to define the supply-chain structure, to set strategic inventory and customer-service targets, to optimize inventory allocation and placement, and to reduce inventory while meeting customer-service targets across the enterprise. The company formed a cross-functional team with representatives from manufacturing, research, finance, marketing, services, and technology. The team identified five areas that needed modeling support for decision making: (1) design of methods for reducing inventory within each business unit; (2) development of alternatives for achieving inventory objectives for senior-management consideration; (3) development and implementation of a consistent process for managing inventory and customer-service targets, including tool deployment, within each business unit; (4) complete evaluation of such assets as service parts, production materials, and finished goods in the global supply network; and (5) evaluation of cross-brand product and unit synergy to improve the management of inventory and risk.

We developed the Asset Management Tool (AMT), a strategic decision-support tool, specifically to address these issues. The integration of AMT with the other asset-management reengineering initiatives has resulted in the successful implementation of extended-enterprise supply-chain management within IBM.

The Asset Management Tool

An extended-enterprise supply chain is a network of interconnected facilities through which an enterprise procures, produces, distributes, and delivers products and services to its customers. As procurement, distribution, and sales have become increasingly global, the supply

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chains of large companies have become deeply intertwined and interdependent. Today's extended-enterprise supply chains are in fact networks of many supply chains representing the interests of many companies, from supplier's suppliers to customer's customers. Because of this interdependency, a company with an extended supply chain performs well only when it collaborates and cooperates actively with its suppliers and resellers.

In high-technology industries, management of the extended-enterprise supply chain becomes very important. At its best, it keeps operating costs low and profits high. But a poorly managed supply chain can reverse that relationship, eroding profits, compromising innovation, and ham-

pering business growth. Early in our efforts, we realized that there were two fundamental keys to overhauling IBM's supply chain. First, we had to reduce and manage uncertainty to promote more accurate forecasts. Second, we had to improve supply-chain flexibility to facilitate quick adaptation to changes in the marketplace. From the outset, we focused on the intrinsic interdependency of an extended-enterprise supply chain. We knew our system would perform as desired only if it reflected the policies and processes used by our suppliers and channels, integrating their value chains with our own. This perspective helped to shape our vision: an integrated modeling and analysis tool for extended-enterprise supply chains. It would be a tool with new methodologies to handle the uncertainties inherent in demand, lead time, supplier reliability, and other factors. It would be scalable, so that it could handle the vast amounts of data describing product structure, supply-chain processes, and component stock information that typify the industry. Finally, the new tool would be equally effective at modeling basic types of supply-chain policies and their interactions, because different companies may use different policies.

We designed AMT to address all of these issues. It is a modeling and analysis system for strategic and tactical supply-chain planning that emerged from various earlier internal IBM reengineering studies [Bagchi et al. 1998; Buckley 1996; Buckley and Smith 1997; Feigin et al. 1996]. It supports advanced modeling, simulation, and optimization capabilities for quantitative analysis of multiechelon inventory systems, along with such features as enterprise database connectivity and internet-based communication. AMT is built on six functional modules: a data-modeling module, a graphical user interface, an experiment manager, an optimization engine, a simulation engine, and a report generator.

The data-modeling module provides a relational data interface, including product structures, lead times, costs, demand forecast and the associated variability information. It has built-in explosion of bills of materials and data-reduction capabilities, and automatic checks for data integrity. It provides access to IBM's global and local operational databases through data bridges.

The graphical user interface (GUI) combines supply-chain modeling with dialog-based entry of supply-chain data. It allows users to build supply networks by dragging and dropping model components, such as manufacturing nodes, distribution centers, and transportation nodes, onto the work space.

The experiment manager facilitates the organization and management of data sets associated with supply-chain experiments. It allows users to view and interactively modify parameters and policies. In addition, it provides automated access to output data generated during experiments and supports a variety of file-management operations.

The optimization engine performs AMT's main function, quantifying the trade-off between customer-service targets and the inventory in the supply network. This module can be accessed from the GUI pull-down menu or called by the simulation engine.

The simulation engine simulates the

performance of the supply chain under various parameters, policies, and network configurations, including the number and location of suppliers, manufacturers, and distribution centers; inventory and manufacturing policies, such as base-stock control, days of supply, build-to-stock, build-to-order, and continuous or periodic replenishment policies. The simulation engine contains an animation module that helps users to visualize the operation of the supply chain or vary parameters and policies while monitoring the simulation output reports.

The report generator offers a comprehensive view of the performance of the supply chain under study, including average cycle times, customer-service levels, shipments, fill rates, and inventory. It also generates financial results, including revenues, inventory capital, raw-material costs, transportation costs, and activity-based costs, such as material handling and manufacturing.

The Optimization Engine

The central function of the optimization engine is to analyze the trade-off between customer-service and inventory investment in an extended-enterprise supply chain. The objective is to determine the safety stock for each product at each location in the supply chain to minimize the investment in total inventory. We view the supply chain as a multiechelon network in which we model each stocking location as a queuing system. In addition to the usual queuing modeling, we incorporated into the model an inventory-control policy: the base-stock control, with the base-stock levels being decision variables. To numerically evaluate such a network, we developed an approach based on decomposition. The key idea is to analyze each stocking location in the network individually and to capture the interactions among different stocking locations through their so-called actual lead times.

We modeled each stocking location as a queue with batch Poisson arrivals and infinite servers with service times following general distributions, denoted as $M^X/G/\infty$ in queueing notation. To do this, we had to specify the arrival and the service processes. We obtained the arrival process at each location by applying the standard MRP demand explosion technique to the production structure. The batch Poisson

AMT embodies a creative coupling of optimization, performance evaluation, and simulation.

arrival process has three main parameters: the arrival rate, and the mean and the variance of the batch size. It thus accommodates many forms of demand data; for instance, demand in a certain period can be characterized by its minimum, maximum, and most likely value. The service time is the actual lead time at each stocking location. The actual lead time at a stocking location can be derived from its nominal lead time (for example, the manufacturing or transportation time) along with the fill rate of its suppliers. In particular, when a supplier has a stock-out, we have to add the resulting delay to the actual lead time. This delay is the time the supplier takes to produce the next unit to supply the order. In our model, we derive the additional delay from Markov-chain analysis.

With the arrival and service processes in place, we can analyze the queue and derive performance measures, such as inventory, back-orders, fill rates, and customer-service levels. The key quantity in the analysis of a stocking location, i, is the number of jobs in the $M^X/G/\infty$ queue, denoted N_i, which can be derived from standard queueing results [Liu, Kashyap, and Templeton 1990]. To alleviate the computational burden in large-scale applications, we approximated N_i by a normal distribution. This way, we need to derive only the mean and the variance of N_i, both of which depend on the actual lead time, which is the service time in the queuing model. Figure 1 shows a snapshot of the dynamics at a stocking location.

The objective of the optimization model is to minimize the total expected inventory capital in the supply network. This total is a summation over all stocking locations, each of which carries two types of inventory: finished goods (on-hand) inventory, and work-in-process (on-order) inventory. The constraints of the optimization model are the required customer-service targets. They are represented as the probability, say 95 or 99 percent, that customer orders are filled by a given due date. Our formulation allows users to specify customer-service targets separately for each demand stream. We first derive the fill rates for each end product to meet the required customer-service target. These fill rates relate to the actual lead times of all upstream stocking locations, via the bills-of-materials structure of the network, and to the actual lead times. The model thus captures the interdependence of different stocking locations, in particular the effect of base-stock levels and fill rates on customer-service. Related models in supply-chain and distribution networks include those of Lee and Billington [1993], Arntzen et al. [1995], Camm et al. [1997],

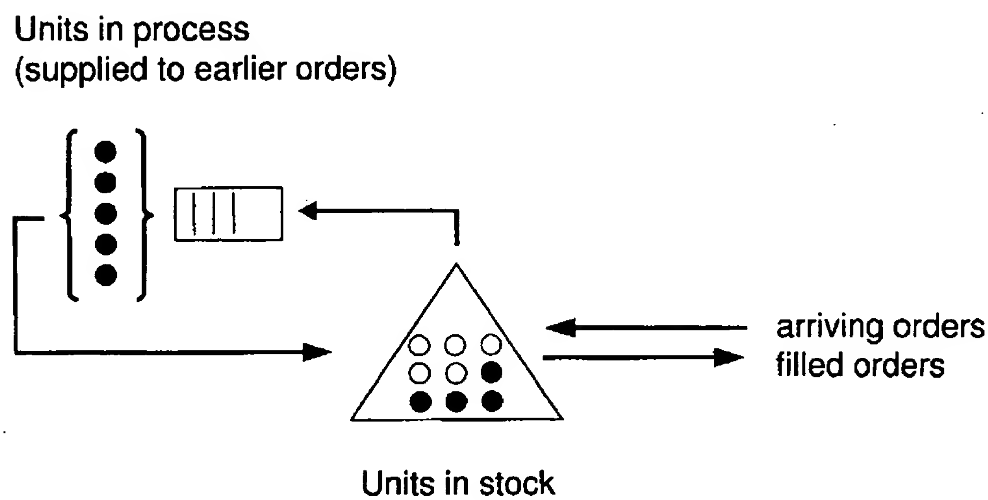

Figure 1: In this snapshot of the system dynamics at a stocking location, the base-stock level is nine, and when there are four units in stock, the other five units have been supplied to earlier orders, which translates into the five jobs in process.

Kruger [1997], Graves, Kletter, and Hetzel [1998], and Andersson, Axsaeter, and Marklund [1998].

To allow fast execution of the optimization, we derived analytical gradient estimates in closed form and implemented a gradient search algorithm to generate optimal solutions. Technical details of this work are presented by Ettl et al. [1998] and in the Appendix. In addition to the gradient search, we developed a heuristic optimization procedure based on product clustering. To validate the solution approach, we compared it against exhaustive searches for test problems of moderate size. For large-scale, industry-size applications, the model has been extensively tested at several IBM business units.

The Simulation Engine

The simulation engine allows users to simulate various supply-chain policies and in particular to verify and fine-tune the performance of the solutions generated by the optimization engine. We built the simulation engine upon SimProcess [Swegles 1997], a general-purpose business-process simulator that was developed jointly by IBM Research and CACI Products Company. The simulation engine preserves the capabilities of SimProcess while adding a supply-chain modeling functionality. Specifically, it provides modeling functions for the following supply-chain processes:

—The customer process represents outside customers that issue orders to the supply chain, based on the modeled customer demand. It can also model information about the desired customer-service target and priority for the customer.

—The manufacturing process models assembly processes, buffer policies, and replenishment policies. It can also be used to model suppliers.

—The distribution process models distribution centers and can also be used to model retail stores.

—The transportation process models transportation time, vehicle loading, and transportation costs.

—The forecasting process represents product forecasts, including promotional and stochastic demand, for future periods.

—The inventory-planning process models periodic setting of inventory target levels. Underlying this process is the AMT optimization engine that computes recommended inventory levels at the various stocking locations in a supply chain based on desired customer-service target.

The simulation engine allows the user to vary a set of input parameters while monitoring output reports to obtain the best set of output values. All input and output parameters reside in the AMT modeling database. Users provide input parameters for the simulation in the form of random variables with stochastic distributions; these include manufacturing lead times, transportation times, material-handling delay times, demand forecasts, product quantity required in a bill of material, and supplier reliability. The stochastic distribution functions supported include beta, Erlang, exponential, gamma, normal, lognormal, Poisson, triangular, uniform, Weibull, and user-defined distributions.

We designed the simulation engine to enable scenario-based analyses in which supply-chain parameters, such as the number and location of suppliers, manufacturers, and distribution centers, inven-

tory levels, and manufacturing, replenishment, and transportation policies (build-to-plan, build-to-order, assemble-to-order, continuous replenishment, periodic replenishment, full truckload, less-than-truckload, and so forth) are varied across simulation runs. For each simulation run, the user can specify a planning horizon, the number of replicating scenarios (sample runs), and a warm-up period during which statistics are not retained. The length of the planning horizon depends on the particular application in question and the availability of historical demand forecasts. We typically choose a horizon that is between six and 12 months.

The simulation-run outcome is in the form of measurement reports that can be generated for turnaround times, customer-service, fill rates, stock-out rates, shipments, revenue, safety stock, and work-in-process. To analyze financial impacts, users can employ the following items, all of which are monitored during the simulation: cost of raw material; revenue from goods sold; activity-based costs, such as material handling and manufacturing; inventory-holding costs; transportation costs; penalties for incorrectly filled or late orders delivered to customers; credits for incorrectly filled or late deliveries from suppliers; cost of goods returned by customers; and credits for goods returned to suppliers.

System Integration and Technical Innovations

We integrated the six functional modules of AMT in a system architecture that is flexible enough to accommodate users' varying computational needs. The architecture is based on a client-server programming model in which one can conduct experiments using the resources of a computer network (Figure 2). The AMT client side provides a set of functions for viewing the graphical user interface and dialog-based data entry. The AMT server side, which typically resides on a powerful workstation or midrange computer, provides the full modeling and analysis functionality. For users with access to low-powered computers, such as laptops, we developed an architecture in which the AMT client side is implemented as a platform-independent Java application or applet; web-enabled clients allow users to access AMT through a web browser.

To manage supply-chain operations, AMT requires data about the different stages and processes that products go through. This data is accessible through a relational modeling database that is connected to the server through a relational interface. The database stores the information associated with the various modeling scenarios, including the supply-chain structure, product structure, manufacturing data, and demand forecasts. The product structures are derived from a top-down bills-of-materials explosion that is processed for each end product. We extracted all product data from corporate databases and from local site data sources.

To facilitate data extraction, we developed a number of database connectivity modules that provide automated database access, extract production data, and feed them into the modeling database. All connectivity modules have built-in bills-of-materials explosion functionality. To detect inconsistencies in data recording caused by missing or incomplete informa-

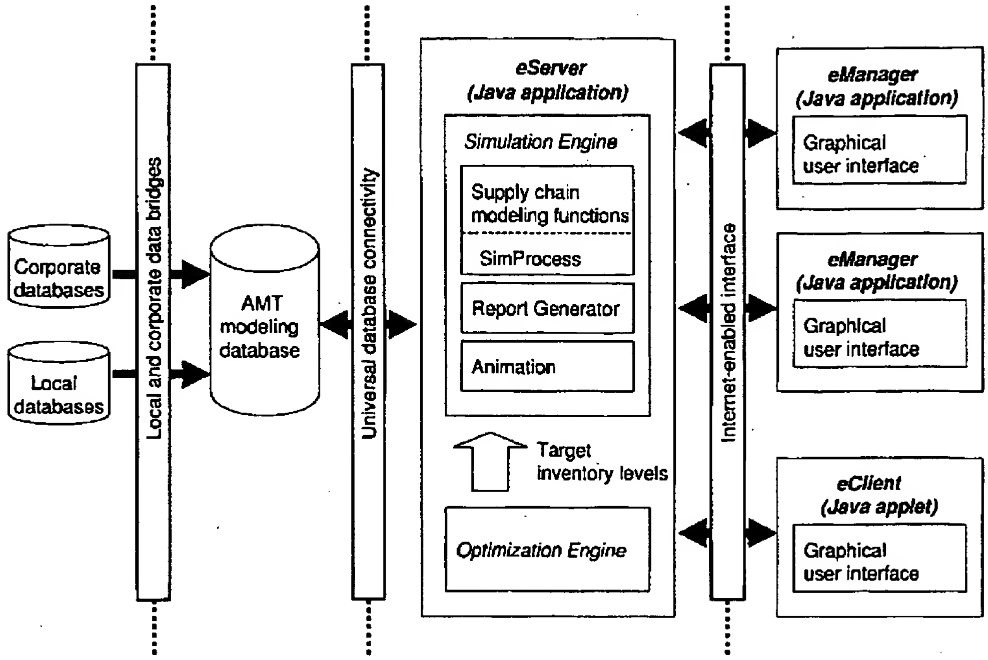

Figure 2: AMT is implemented using a client-server architecture in which the modeling functionality is separated from the graphical user interface. The modeling engines reside on a server computer (eServer). The graphical user interfaces are piped to client computers that are implemented as either Java applications (eManager) or Java applets (eClient). The AMT modeling database can be accessed through a relational database interface. It contains such supply chain data as bills of materials, demand forecasts, lead times, costs, inventory policies, and customer-service requirements. Local and corporate data bridges provide automated access to enterprise data sources.

tion pertaining to the bills of materials, we added database consistency checks that generate missing data reports and reduce the data set to a consistent level that can be downloaded to the modeling database. The data-collection process allows the user to supply missing data in relational tables that can be merged with the output of the explosion. To keep the complexity of the bills-of-materials explosion manageable, we implemented data-reduction routines through which one can eliminate noncritical components automatically, based on the item's value class or annual requirements cost.

AMT's graphical user interface allows modelers to build supply networks for a variety of supply chains by dragging and dropping generic supply-chain components on the workspace (Figure 3). Sophisticated algorithms are encapsulated in the components. For instance, clicking the "PSG manufacturing" node will bring up screens for the user to specify parameters and policies, such as delay time, manufacturing lead times, bills of materials, and such manufacturing policies as build to order or build to plan. AMT also supports

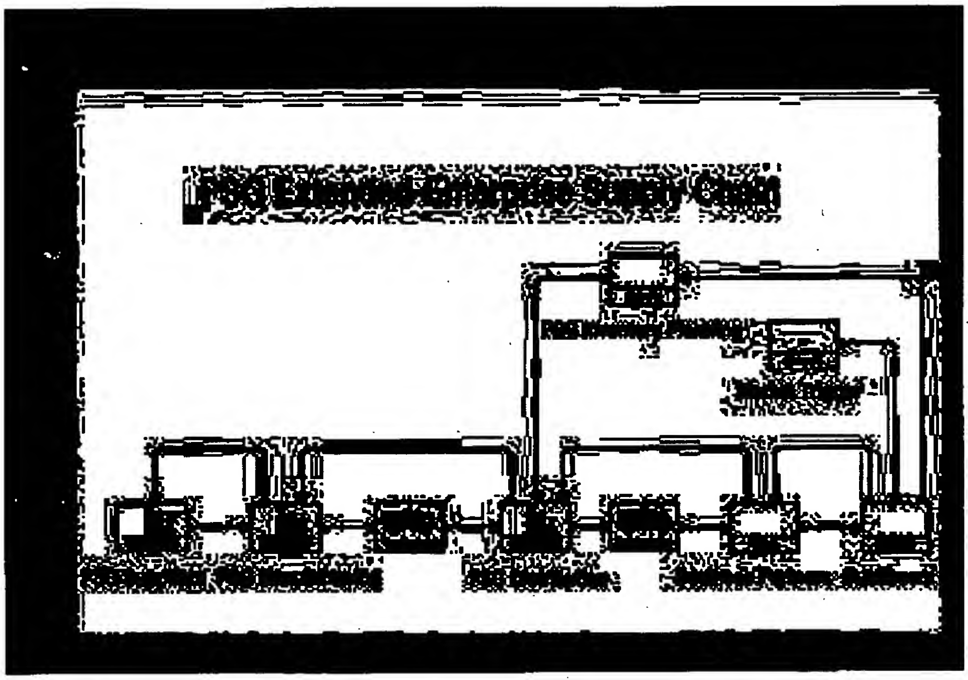

Figure 3: AMT provides a graphical user interface that allows one to interactively construct supply chain scenarios. In this example of an extended-enterprise supply chain, business partners (PSG Business Partners) send orders to a distribution center (PSG Distribution). The distribution center processes the orders and sends products to a transportation node that ships the products to the business partners. The distribution center needs to replenish its stock from time to time, so that it sends replenishment orders to the manufacturing site (PSG Manufacturing) that assembles finished products. The manufacturing site in turn replenishes its parts supply by sending orders to its suppliers (PSG Suppliers). An inventory-planning node (PSG Inventory Planning) representing the AMT optimization engine computes optimal inventory levels for the distribution center based on forecasts of customer demand.

hierarchical process modeling. The user can drill down to include other layers of the supply chain, adding scalability to the modeling approach. The customer node captures demand, forecast, and customer-service requirements. We built in animation to help users visualize the supply-chain activities of orders, goods, and trucks moving between nodes. As the simulation is running, users can view reports, such as service or inventory reports, to see the current status of the simulation. In addition to these real-time reports, AMT also offers the financial and performance reports that we discussed earlier.

An important feature of AMT is the complementary functionality of the optimization and simulation engines. With the optimization engine, the user can perform fast yet very deep what-if analyses, which are beyond the capability of any standard simulation tool. With the simulation en-

gine, the user can invoke the inventory module to perform periodic recalculations of optimal inventory levels while simulating dynamic supply-chain processes and policies. The user can run simulations on optimized solutions, observing how different supply-chain policies at different locations affect the supply chain's performance. Simulation results can also be used to adjust parameters of the simulation or optimization runs. An automated interface between the simulation engine and the optimization engine allows users to invoke optimization periodically during a simulation run, for example to recalculate target inventory levels according to the latest forecast of demand. Users can also use the optimization engine to periodically generate build plans in a mixed push-pull manufacturing environment, taking into account service targets and system uncertainty.

In summary, AMT embodies a creative coupling of optimization, performance evaluation, and simulation, integrated with data connectivity and an Internet-enabled modeling framework. This makes it a powerful and versatile tool for capturing the stochastic and dynamic environment in large-scale industrial supply chains. We model extended-enterprise supply chains as networks of inventory queues, using a decomposition scheme and queuing analysis to capture the performance of each stocking location. We developed multiechelon, constrained inventory-optimization algorithms that use conjugate gradient and heuristic searches for efficient large-scale applications. We developed a supply-chain simulation library consisting of an extensive set of supply-chain processes and policies for modeling various supply-chain environments with little programming effort. It offers performance measures, financial reports, and activity-based costing down to the level of individual stock-keeping units. It also gives the user a way to validate and fine-tune supply-chain parameters based on analytical results.

Extended-Enterprise Supply Chain Management at IBM Personal Systems Group

The IBM Personal Systems Group (PSG) is responsible for the development, manufacture, sale, and service of personal computers (for example, commercial desktops, consumer desktops, mobile products, workstations, PC servers, network PCs, and related peripherals). PSG employs over 18,500 workers worldwide. Sales and marketing groups are located in major metropolitan areas, with manufacturing plants located in the United States, Latin America, Europe, and Asia. In 1998, PSG sold approximately 7.7 million computers under such brand names as IBM PC, Aptiva, ThinkPad, IntelliStation, Netfinity, and Network Station.

Increased competition from such PC manufacturers as Dell and Gateway, which use a direct, build-to-order business model, prompted PSG in 1997 to reevaluate its business practices and its relationships with its supply-chain partners. The goal was to design and implement a hybrid business model, one that incorporated the best features of the direct model (build to order, custom configuration, and inventory minimization) and the best features of the indirect model (final configuration, high customer service, and support), sell-

ing products through multiple channels.

PSG formed a cross-functional team in April 1997 with the task of quantifying the relationship between customer service and inventory throughout the extended supply chain under the existing business model and under various proposed channel-assembly alternatives. We used production data from a subset of PSG's commercial desktop products to develop a baseline supply-chain model in AMT. The model was triggered by end-user demand, reseller ordering behavior, IBM manufacturing and inventory policies, supplier performance, and lead-time variability. We collected actual end-user sales data for 22 reseller locations over five months. Resellers' ordering behavior was influenced by many factors, such as gaming strategies, marketing incentives, confidence in supplier reliability, and stocking for large customer purchases. Modeling each individual activity would have been too complex. Our model captured the aggregate ordering for each PSG reseller by substituting alternative ordering policies, representing current levels of sales activity in the channel. For example, if a particular reseller held an average of 60 days of inventory, the model established a target base-stock level representing 60 days of channel inventory for this reseller. To see what would happen if resellers changed their ordering policies, we changed the levels of channel inventory in the AMT model and ran different what-if scenarios. For each ordering policy, we assumed that a reseller would stock a product at a given level of days of supply.

During the normal course of business, PSG forecasts its manufacturing volumes over a rolling 13-week horizon. The current week's forecast becomes the build plan, which then pushes products built at PSG's manufacturing sites to the distribution warehouse where they are held until the products are eventually ordered, or pulled, by a reseller. This type of replenishment policy captured the logic of PSG's hybrid push-pull manufacturing and ordering system in which PSG built products to a forecast and held them as finished goods in the warehouse until it received orders from its resellers. This system is not a true pull system because product availability influences reseller ordering. Likewise, the system is not a true push system because the backlog of resellers' orders influences the schedules at PSG manufacturing sites. To effectively capture variability caused by component shortages, capacity constraints, and requirements for minimum lot sizes, we analyzed the range of the 13-week forecasts.

> PSG's channel look-back expenses dropped by more than $100 million.

PSG set a service target for customer deliveries of three days, 95 percent of the time, which translated directly into the customer-service constraint required by the AMT optimization engine. Combining the simulation engine with the optimization engine, the model recalculated the base-stock levels every week, according to the latest available forecast of demand so that customer orders could be filled within three days 95 percent of the time. This replenishment policy formed the basis for PSG's supplier orders for components and

subassemblies and for its subsequent manufacturing activity. In Phase 1 of the project, we used a reduced data set to construct a simplified prototype model of PSG's supply chain to test assumptions, to investigate alternative modeling algorithms, and to better understand possible limitations of the AMT application.

In Phase 2 of the project, we developed more detailed modeling scenarios to vary channel inventory and to incorporate a channel-assembly policy at the resellers. PSG delivers to its resellers two types of products, (1) standard machine-type models (MTMs), which are fully configured and tested computers, and (2) so-called open-bay machines, which are nonfunctional, basic computers without such preconfigured components as memory, hard files, and CD ROMs. These open bays allow resellers to assemble machines according to specific customer requirements. We found that some resellers converted open bays into standard MTMs as needed and then sold them to their customers. We refer to this as an example of flexibility because resellers can use their current open-bay inventory to fill orders for standard MTMs, instead of stocking open bays exclusively to fill orders for nonstandard MTMs. Other resellers stockpiled open-bay inventory, and if they needed standard MTMs to fill an order, they would reorder from PSG instead of configuring an open bay already in stock (an example of inflexibility). Both methods affect inventory and customer service. Because reseller flexibility could not be defined accurately, we designed different sets of simulation experiments with the intent to bound, or frame, the true impact of channel assembly within the two extreme cases of 100 percent reseller flexibility and 100 percent reseller inflexibility.

We validated the accuracy of the AMT models by comparing the outputs of the simulation runs to historical PSG data. We adjusted our modeling assumptions and parameters as necessary and ran multiple simulations using different parameters and policies. The key results of the study can be summarized as follows:

—Implementing channel assembly based on PSG's existing product structure, low volume environment, and present supply-chain policy reduces inventory very little (inflexible reseller channel behavior).

—Allowing resellers to configure any MTM from their stock of components could improve customer service by two percent and simultaneously reduce inventories by 12 percent (flexible reseller channel behavior).

—Consolidating the demand at 22 configuration sites into three large hubs could improve customer service by six percent and reduce inventories by five percent.

—Based on the existing push-pull supply-chain policy, PSG can reduce channel inventory by 50 percent without affecting its customer-service level. The overall supply-chain inventory levels were far in excess of the optimum needed to maintain PSG's service target.

This and subsequent projects brought together four functional groups—marketing and sales, manufacturing, distribution, and development—to seek a company-wide consensus on PSG's strategic direction and subsequent actions. Our studies contributed directly to PSG's advanced fulfillment initiative (AFI), an effort to in-

crease flexibility in the reseller channel by improving parts commonality in PSG's product structure [Narisetti 1998]. Also, PSG management endorsed the reduction of the number of configuration sites, as a result of changing channel price-protection terms and conditions. The specific terms and conditions were tied to the output of the AMT model, and they were implemented in November 1997 after a series of related enhancements to the logistics process.

PSG has based many of its decisions on how to prioritize project deployment and manage channel inventory on the results of subsequent AMT analyses. While the analysis that drove PSG's initial business transformation was conducted in 1997, the 1998 business benefits were substantial.

The more accurate a reseller's forecasts, the higher the level of service.

PSG reduced its overall inventory by over 50 percent from year-end 1997 to year-end 1998. As a direct consequence of this inventory reduction, PSG's channel look-back expenses dropped by more than $100 million from 1997 levels. Look-back expenses account for payments to distributors and business partners that compensate for price actions on the inventory they are holding. In addition, by selling products four to six weeks closer to when the components are procured, PSG saved an additional five to seven percent on product cost. This equates to more than $650 million of annual savings.

In the months following the original assessment, we conducted further supply-chain studies, including analyses that (1) incorporated the supply chains of business partners; (2) modeled additional geographies; (3) assessed the impact on inventory and customer service of delaying final assembly to the reseller's distribution facilities; and (4) estimated the impact on inventory of reducing manufacturing cycle times. These studies have helped PSG's business partners make more informed decisions on supply-chain policy. In particular, they have led IBM and its major business partners to establish a colocation policy. In colocation, a business partner locates its distribution space inside of IBM, eliminating the need for costly handling and transportation among different sites. Finally, because we found that forecast accuracy greatly affected inventory and customer service, PSG used the AMT to determine the level of service it would promise to its business partners, based on their ability to provide accurate forecasts. The more accurate a reseller's forecasts, the higher the level of service PSG would provide to that reseller. This policy is unprecedented in the industry and has been favorably received by PSG's business partners. Overall, PSG believes that the AMT has been an invaluable asset in developing and implementing world-class supply-chain-management policies.

Other AMT Applications Across IBM

AMT has also been applied and deployed in other IBM manufacturing divisions, including the printing systems division (PSC), the midrange computer division (AS/400), the office workstation division (RS/6000), the storage systems division (SSD), the mainframe computer division (S/390), and PSG's European mar-

ket. A number of PSG's business partners have used AMT, including Pinacor, GE Capital, and Best Buy. IBM's Industry Solution Unit uses the tool externally for consulting engagements. Following are brief descriptions of three recent AMT engagements:

The IBM Printing Systems Company (PSC) is a leading supplier of printer solutions for business enterprises. The product line includes printers for office printing to high-volume production printing. The company employs approximately 4,550 people, with total gross revenue for 1998 of $1.95 billion. In 1996, PSC conducted an intensive testing process on the AMT over a five-month period. In its assessment report, the testing team concluded that AMT produces accurate results, provides productivity improvements over existing supply-chain-management and inventory tools, and improves PSC's precision in validating and creating inventory budgets and turnover objectives. PSC then used AMT to study the effects of forecast accuracy, product structure, the introduction of a new distribution center, and different business scenarios on the performance of the supply network for different product families. In one of the cases alone, it reported inventory savings of $1.6 million, which represented 30 percent of the total inventory holding cost.

Financial savings amount to more than $750 million at PSG in 1998.

IBM's AS/400 division manufactures midrange business computers and servers, providing more than 150 models and upgrades with up to 1,000 features. Assembling these systems requires several thousand unique part numbers, approximately 1,000 of them used at the highest level of assembly just prior to building a complete system. Providing customers with the flexibility to customize the equipment they order by selecting features creates manufacturing complexity and efficiency challenges. The division used AMT to analyze and quantify the impact on inventory and on-time delivery of feature reduction, feature substitution, parts commonality, and delayed customization. The analysis showed that eliminating low-volume parts would improve inventory turnover by 15 percent and that substituting and postponing their final assembly would improve inventory turnover by approximately 30 percent. The AS/400 division has reduced its feature count by approximately 30 percent since 1998 with steady growth in total revenue.

In 1995, IBM established a quick-response service program to provide rapid delivery for customers buying selected mid-range computer memory, storage, and features. In September 1998, IBM instituted the quick-response program as a front end to provide real e-commerce for our large business partners. IBM used AMT to analyze the trade-off between service and inventory in choosing an optimum performance point. It later used it to assess the impact of the quick-response program on allocating inventory between manufacturing and distribution centers. The results helped IBM to maximize business efficiency and contributed to doubling the growth of quick-response revenue in 1998.

Conclusions

The AMT effort uses advanced OR techniques and combines technical innovations with practical and strategic implementations to achieve significant business impacts. IBM has used AMT to address a wide range of business issues, including inventory management, supply-chain configuration, product structure, and replenishment policies. AMT has been implemented in a number of IBM business units and their business partners. Financial savings through the AMT implementations amount to more than $750 million at PSG in 1998 alone. Furthermore, AMT has helped IBM's business partners to meet their customers' requirements with much lower inventory and has led to a colocation policy with many business partners. It has become the foundation for a number of supply-chain-reengineering initiatives. Several IBM business partners view the AMT analyses as key milestones in their collaboration with IBM in optimizing the extended-enterprise supply chain.

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Executive summaries of Edelman award papers are presented here. The complete article was published in the INFORMS journal Interfaces [2000, 30:1, 7-25]. Full text is available by subscription at http://www.extenza-eps.com/extenza/contentviewing/viewJournal.do?journalId=5

How Low Can You Go?

Using Simulation to Determine Appropriate Inventory Levels

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Abstract

Proper inventory levels are critical to maximizing your manufacturing system's performance; but what level of inventory is best? Too much inventory will add cost and increase cycle time. Too little inventory will jeopardize total output. Achieving good system performance depends upon a very difficult and often non-intuitive exercise in balancing capacity against demand. This exercise is made all the more difficult by the random variability inherent in any real system. Fortunately, there is a tool – discrete event simulation - that gives you the very valuable ability to understand how variability and randomness affect your process. Perhaps most importantly, however, simulation allows you to experiment with various inventory policies in determining the best balance for your particular system, all without having to implement non-optimal choices in the real system.

After a review of basic issues in inventory management, we provide an overview of simulation in this context. We will discuss simple simulation examples as well as case studies from manufacturing, service, and supply chain analysis. We conclude by offering advice for implementing simulation in your organization.

1 Introduction

Inventory, for our purposes here, is defined as a collection of any item or resource used in an organization to produce manufactured goods. We will look at five types of inventory that are commonly addressed by lean initiatives: raw materials, work-in-process, finished goods, production capacity, and labor. Once the purpose of inventory is understood, we can then make efforts to minimize inventory which will in turn help to improve production cycle times and lower inventory.

As an analytical planning tool, simulation naturally lends itself to lean analysis. Simulation mimics the dynamics and randomness of manufacturing processes. This variation is the main reason inventory exists in most systems. Through the proper use of simulation technology, organizations can determine the lowest levels of inventory required to absorb the variability found with any a system.

2 Purpose of Inventory

Variation in all its forms is the source of inventory build-up in virtually all systems. Not all inventory build-up is negative, and is in fact an effective means of coping with variation itself. In this section, we review the specific ways in which inventory may arise from variability in everything from raw material prices to production speeds.

2.1 Raw Materials

Raw materials feed the system and keep it moving. Without it, production must eventually stop. On the other hand, excess raw materials can strain the inventory holding capacity of the system as a whole. As with all else, finding the right balance is key. The idea is to have the lowest level of inventory that will still allow you to meet your objectives. The following is a list of the reasons for holding inventory.

2.1.1 Take Advantage of Ordering in Economic Quantities (Volume Discounts)

In many cases, there may be substantial savings when raw materials are ordered in larger quantities than may be immediately required in production. These savings must be balanced against the costs of holding the resulting raw materials inventory.

2.1.2 Provide a Safeguard Against Variable Lead Times And Quality

In order for the production process to continue smoothly, raw materials must be available when needed by the system. This is not always as simple as it sounds, however, as materials often come from independent vendors. If the raw materials have a variable ordering lead-time, it is wise to hold some additional inventory as a hedge against those cases in which the ordering lead-time may be longer than expected. A related concern may occur when the raw materials supplied may vary in quality. If a larger-than-expected portion of the raw materials must be rejected on the basis of quality, a stock-out could occur. Again, a company may choose to hold a bit of additional inventory of this material as a safeguard.

2.1.3 Price Speculation

As with most other elements of a system, the price of raw materials may be highly variable. In such cases, it is often common practice to 'stock-up' on raw materials that are currently at a low point on their price scale. This practice, while economically favorable, can lead to excess raw material inventory.

2.2 Work-in-Process

Some level of work in process is a desirable element in many systems, and may arise for a variety of reasons. The most principal of those reasons are discussed below.

2.2.1 Buffer Variability in Production Rates

Consider two sequential operations each working at different rates and with different degrees of variability. With no Work-in-Process (WIP) buffer between the operations, the second operation would be highly dependent on the output of the first operation. If the first operation is significantly slower, or is experiencing an unusually slow processing time, the second operation is blocked. Similarly, if the first operation finishes an item before the downstream operation is ready to accept it, the first operation must stop working until it can pass on the completed item. Including a buffer between these two operations to accumulate WIP allows for the operations to continue operating independently.

2.2.2 Allow for Flexibility in Production Scheduling

Changeovers that result when one product type follows another may be a significant aspect of the system's overall performance. In such cases, it is often possible to minimize the effects of changeovers through clever production scheduling. The more product types that are available in WIP inventory at each stage of the production, the more options there are for production scheduling. As a result, WIP is sometimes deliberately built in to allow for this flexibility.

2.2.3 Absorb Different Labor Shift Patterns

Variations in labor availability can be caused by many factors, such as seasonal increases in demand, or shortages due to strike. Keeping some additional WIP around labor-critical phases of the production can be instrumental in absorbing the effects of variation in labor availability .

2.2.4 Absorb Unexpected Equipment Down-Times

Everything breaks eventually. Murphy's law, of course, says that equipment will go down at the most inopportune time. Maintaining WIP inventory of the product produced by the more unreliable operations will allow both upstream and downstream operations to continue while the machine is being repaired.

2.3 Finished Goods

It is most manufacturer's ideal to sell all inventory as fast as it is produced. At the same time, good customer service typically dictates that no customer should be made to wait for a product. After all, the customer may simply decide to go down the street to your competitor if you do not have the goods available. The compromise between these situations typically involves some amount of finished goods inventory.

2.3.1 Provide a Safeguard for Variation in Demand

Consumer demand patterns have always been fickle. Precise demand levels are impossible to predict even with the best forecasting methodologies. Safety stock allows you to be prepared in the case of higher than expected demand. However, it is a trade-off between customer service and inventory holding costs

2.3.2 Cover for Seasonality or Promotion

Occasionally, it is possible to know with reasonable certainty that demand is about to increase. This may be due to an upcoming high demand season or to a promotion. It is common for peaks in demand to drastically outpace available production capacity. In these periods, additional finished goods stock must be built-up in advance to cover future demand.

2.3.3 Covers Goods in Transit

Many companies consider goods in transit as inventory. Commonly referred to as pipeline inventory, goods in transit can be substantial for commodities (large volume), or high value products. Goods with high turnover rates can also carry large pipeline inventory costs.

2.4 Production Capacity

Although it is common refer to inventory strictly as raw materials, work-in-process, and finished goods, advocates of lean manufacturing also consider production capacity as a type of inventory that can be examined and improved.

2.4.1 Capital Equipment

If unused capital equipment can be successfully removed without affecting the fundamental goals of lean manufacturing, then it represents an opportunity. An example could be redundant equipment, used only in case of equipment failure.

2.4.2 Replacement Parts, Tools, and Supplies

Inventory of replacement parts, tooling, and production supplies is yet another type of inventory that is subject to analysis. Proper justification for these items can help to ensure adequate levels of availability.

2.5 Labor

In some cases, skilled labor may be considered as a type of inventory that could be reduced. The organization must compare the trade-off between recruitment and training costs with the cost of holding the labor through underutilized time-periods. As with all other types of inventory, holding policies

become very important. In fact, such policies may be become even more important in the case of labor, as the future availability of skilled or specialized labor may be uncertain. During peak economic times, the availability of labor is commonly a primary constraint in many organizations.

3 How Can Simulation Help?

Simulation, because it is a system-wide detailed approach, can take into account all types of inventory and their detailed management rules. Simulation is flexible and powerful enough to model any dynamic system in which one element of the system may dramatically effect the operation and performance of another element. Because simulation models accurately reproduce the logic and random effects of a system, they can also accurately portray inventory levels as they change over time.

3.1 Overview of Discrete Event Simulation

3.1.1 What is it?

Most manufacturing systems are best modeled using a very specific kind of simulation known as discrete event simulation (DES). In this type of simulation, individual entities in the system are represented as unique 'work items,' each with an appropriate set of attached identifying characteristics. In DES, everything is event driven, and each event is treated individually. Because events are individualized, it is possible to have enormous control over the way in which each event and the associated items flow through the system. This control, in turn, makes it possible to create very accurate models.

What, then, is an event? That all depends on the system you are considering. If you are modeling a telephone contact center, for example, an event could be the arrival of a customer's call into the system, or an agent picking up a call, or a customer choosing to abandon a call. A manufacturing model, on the other hand, might involve events such as passing a certain raw material through a tooling machine, or moving an item from a finished goods inventory to the shipping department.

Discrete event simulation, or just simulation for short, can help solve a number of critical business and logistic problems faster and more accurately than any other method of analysis. Wherever a decision is required involving a complex or dynamic process, simulation is typically the modeling tool of choice. In fact, it is often the only analytical tool that can provide any degree of accuracy in such systems. Simulation is regularly used to:

- Test proposed changes while avoiding significant capital expenditures
- Evaluate alternatives for improving productivity and reducing operating costs
- Improve customer service
- Increase utilization of resources and equipment
- Effectively communicate new ideas and designs to financial decision makers

A computer simulation model can be thought of as a virtual representation of a system or process where the goal is to mimic, or simulate, a real system so that you can explore it, perform experiments on it, and understand it without having to make changes to the real system. This, of course, translates into the ability to identify bottom line opportunities for system improvement without spending a fortune in the examination process. It also allows you to examine the expected behavior of systems that have yet to be created.

Simulation is used to help people make decisions and to communicate the effects that those decisions have on the given system. It allows the comparison of different sets of scenarios so that the decision-maker can formulate judgments after considering all possible angles. Simulation languages, such as

SIMUL8™, show the flow of work through a system, one event at a time, with all the key interactions shown graphically on the computer screen. These graphics can be animated and the results output in hardcopy for analysis and examination.

Simulation is well-suited to any situation involving a process flow. Because it is not dependent upon any particular analytical formula, simulation is not limited by restrictive modeling assumptions. Instead, it can be used to represent complicated dynamic interactions. Perhaps the greatest strength of simulation, however, lies in its ability to accurately reflect the randomness that we see in the real world. Some of the areas naturally involving randomness include arrival patterns, service times, travel times between stages in a network, and many more. The ability to model this variation, therefore, allows us to better understand how a system will function under a variety of scenarios.

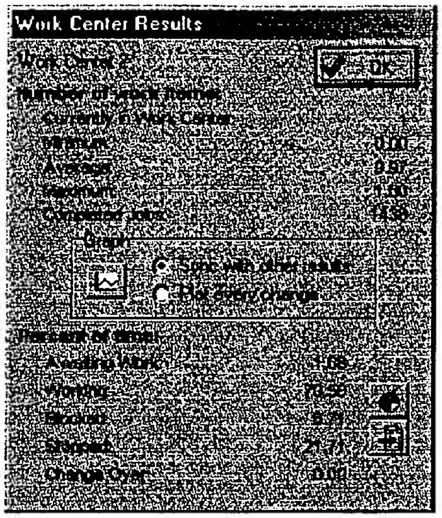
As an example of how important randomness can be in a system, consider a grocery store line with a single cashier. If we know that customers arrive exactly every 10 minutes, and that the cashier can process a single customer in exactly 9 minutes, it is easy to see that no troublesome line would ever form. Of course, that's not what happens in the real world. Instead, there is wide variation both in how customers arrive and in how long they take to be processed. At 5:30 p.m. on a weekday, customers arrive much more frequently than normal. In addition, they arrive with a varying number of groceries in their carts. Customers range from someone stopping by to pick up a gallon of milk, to a customer stocking up for the week. The length of the cashier's line will vary dramatically depending upon how many items each customer has, and the order in which the customers arrive.

3.1.2 Simulation Results

Once an appropriate simulation model has been developed, it will naturally produce a wide range of useful performance statistics. This section will highlight many of the results that common simulation software packages produce. For purposes of demonstration, the results and terminology in the following discussion are based on SIMUL8™, a very popular discrete event simulation package. Analogous results can be found in all full-featured DES packages. We will discuss the results obtained by the three most common objects in SIMUL8: buffers, work centers, and work exit points.

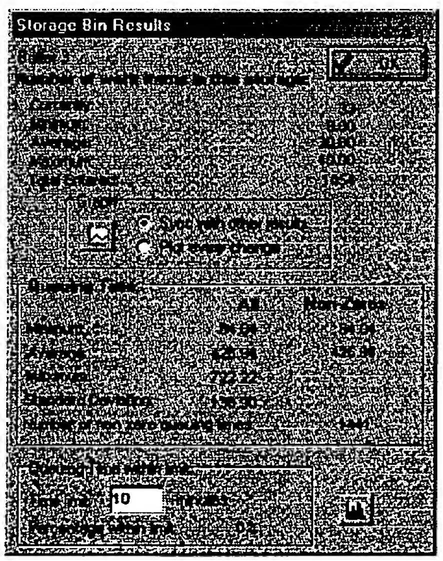
Buffers (also called storage bins or queues) typically collect two types of results, time in queue and queue length. For lean initiatives, the minimum time in the queue is of particular interest as this represents the amount of time that can be eliminated from the system without affecting the downstream operation. This also represents the improvement in total cycle time that is possible. Alternatively, minimum inventory level represents the number of units of inventory that could be eliminated without affecting downstream operations.

Figure 1



Work centers are active objects that pick up an entity and process it for a (possibly random) processing time. Work centers produce utilization statistics including time spent waiting for work, working, blocked, stopped, and changeover time. If a utilization statistic relates to a bottleneck operation, any time spent waiting for work represents scheduling inefficiencies and an opportunity for improvement. For non-bottleneck operations, non-utilized time represents idle capacity that could be eliminated without affecting the overall system's output (lean initiatives (Moore and Scheinkopf)). The blocked statistic represents the percentage of time in which a work center is prevented from discharging its completed items due to a limited downstream inventory capacity.

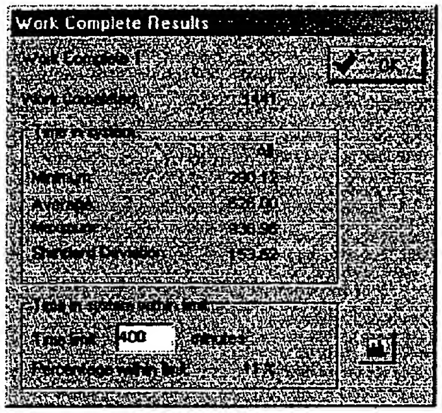
Figure 2



SIMUL8's **work exit point** objects are used to mark the removal of an entity from the modeled system, perhaps to represent that a finished good has left the manufacturing facility. Work exit points collect a very useful statistic for lean manufacturers - time in system. This represents the total cycle time for an

item from start to finish. An example of this would be the time from when a customer places an order to the time it is delivered. Minimizing this result is another common goal of lean manufacturing.

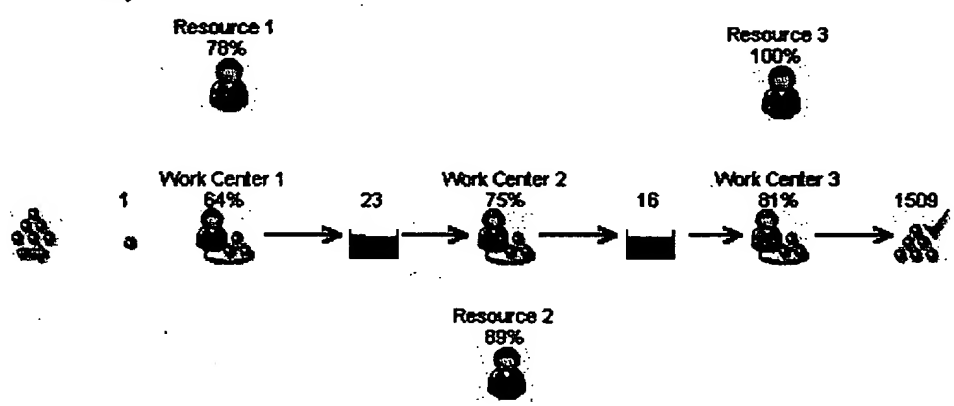
Figure 3



3.1.3 Example – Maximum Buffer Size

Figure 4 shows a simple simulation model of a 3-work center, 2-buffer operation where work is processed in sequence (Work Center 1, Work Center 2, Work Center 3). The model is used to demonstrate how important buffering is to the performance of a system. Without adequate work-in-process, work centers 2 and 3 may become starved for material and lose precious production time. However, because work center 3 is the bottleneck operation (having the longest process time), work centers 1 and 2 have the potential to continually build inventory.

Figure 4



Specifically, this simple example model above takes into account the following random and dynamic elements:

- Variable process times (Table 1)
- Reliability parameters (Table 1)
- Staggered labor schedules for each machine (Table 2)

Table 1

(All times in minutes)	Process Time Log Normal		MTBF Exponential	MTTR Erlang	
	Average	St. Dev.	Average	Average	K
Work Center 1	8	2	200	45	15
Work Center 2	9	2	200	45	15
Work Center 3	10	2.5	200	45	15

Table 2

	Work Center 1		Work Center 2		Work Center 3	
	Start	End	Start	End	Start	End
Shift 1	00:00	03:00	00:30	03:30	01:00	04:00
	03:15	06:00	03:45	06:30	04:15	07:00
	06:30	08:00	07:00	08:30	07:30	09:00
Shift 2	08:00	11:00	08:30	11:30	09:00	12:00
	11:15	14:00	11:45	14:30	12:15	15:00
	14:30	16:00	15:00	16:30	15:30	17:00
Shift 3	16:00	19:00	16:30	19:30	17:00	20:00
	19:15	22:00	19:45	22:30	20:15	23:00
	22:30	00:00	23:00	00:30	23:30	01:00

The purpose of this model is to investigate the effects of the dynamic and random elements in an effort to impose maximum buffer constraints. By setting maximum buffer sizes, work centers 1 and 2 will be prevented from working. Using simulation, we can vary capacity limitations to investigate the effects on throughput, cycle time, and utilization. For example, Figure 4 is a screen capture of the simulation model at the conclusion of one scenario. The results of this simulation show a total production of 1509 units in 14 days.

In studying simulation models, it has traditionally been necessary to vary the parameters manually from one scenario to the next. Each scenario required a trial of several runs. Results from various scenario trials were then collected and compared to find good quality solutions. Finding an optimal solution could be a laborious, if worthwhile, exercise. With recent advances in simulation optimization algorithms, it is now possible to automate the search for high quality solutions. Companion products are now available for use with simulation languages that allow you to specify an allowable range for input parameter values, as well as a metric for judging the quality of the solution. In our example models, we have chosen to use one such companion product, called OptQuest™ for SIMUL8.

Using OptQuest, we were able to determine the combination of buffer capacities to (1) maximize production and (2) minimize work-in-process. Table 3 shows the total production output for the combination of buffer sizes ranging from 5 to 12 units for Buffer 2 and 18 to 27 units for Buffer 3. The maximum possible production levels are highlighted. Therefore, a buffer combination of 10 and 26 or 9 and 27 will minimize inventory while ensuring maximum production is met. Buffers any larger will not increase production past 1516 but will simply increase cycle time and inventory costs.

Table 3

Production		Buffer 3									
		18	19	20	21	22	23	24	25	26	27
Buffer 2	5	1497	1499	1500	1500	1501	1501	1503	1504	1506	1507
	6	1499	1501	1503	1503	1505	1506	1507	1509	1509	1510
	7	1503	1504	1505	1506	1507	1509	1510	1511	1512	1513
	8	1504	1506	1506	1508	1509	1510	1512	1512	1513	1514
	9	1506	1506	1507	1509	1510	1511	1512	1513	1514	[illegible]
	10	1506	1507	1509	1510	1511	1512	1513	1514	1516	[illegible]
	11	1506	1507	1509	1510	1511	1512	1513	1514	1516	[illegible]
	12	1506	1507	1509	1510	1511	1512	1513	1514	[illegible]	[illegible]

We intend this example to demonstrate the power of simulation on even a small problem with only a few random elements. Without simulation, it would be very difficult, if not impossible, to determine inventory rules that would meet the same objectives.

3.2 Application Areas

The applicability of simulation to various areas or problems is quite remarkable. Almost any process or activity could benefit from simulation, from simple queuing systems to complex manufacturing processes. Below is an overview of the range of simulation applications we have been involved in.

3.2.1 Industries

Although simulation's roots are in manufacturing, specifically assembly lines, its use is extremely widespread. Application areas include, but are certainly not limited to, the industries show in Table 4.

Table 4

Manufacturing	Food and beverage	Military	Service industries
Distribution and transportation	Insurance and banking	Healthcare	Mining
Forestry	Entertainment	Automotive	Electronics
Chemical processing	Telecommunications	Education	Government

3.2.2 Areas within the Organization

Just as there are many industries, there are many areas within an organization in each industry. These stretch the entire span of an organization's many activities including marketing, procurement, shop floor manufacturing, inventory management, order fulfillment, and customer service. Each area will certainly have its own unique issues, but many of the principles will remain the same. Any situation in which demand and capacity must be balanced is well-suited to simulation. This may also include the operating rules and management decisions that go into a process.

3.3 Examples of Lean Simulations

As we have indicated, simulation is extremely well-suited as a tool for lean manufacturing initiatives. The following are a few examples of how simulation is being used to assist organizations in becoming lean.

3.3.1 Supply Chain

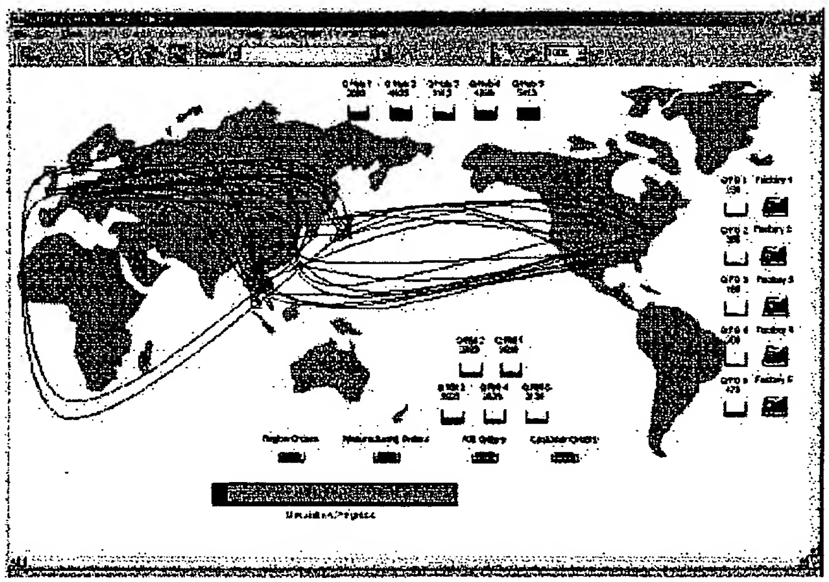
Supply chain analysis is particularly well-suited to simulation because of the interaction of many uncertain and random events. This type of analysis is also commonly targeted by lean advocates because

of the high visibility that inventory has within a supply chain. Common elements in supply chains that make it particularly well-suited to simulation include:

- Uncertain demand
- Dynamics modes of transportation
- Complex inventory holding policies
- Yield
- Variable transportation times
- Obsolescence
- Variable production lead times

Figure 5 displays a screen shot of a simple supply chain model. In this example, dynamic inventory quantities, including both raw materials and finished goods, are tacked and displayed over time. Incorporating variable lead times, customer demand patterns and inventory management policies, the model allows decision makers to understand how changes in policies are expected to affect inventory build-up.

Figure 5



3.3.2 Implementing KanBan Systems

Kanban is a parts-movement system that assists just-in-time production by moving goods from one workstation to another on a production line. Simulation is not only well suited to determining the feasibility of a kanban system but will also assist in determining the configuration and the number of kanbans required to meet production levels while minimizing inventory.

3.3.3 CNC Horizontal Machining Center

Processes that are reliant on product specific tooling become quite interesting as a balance must be struck between product variety and low work-in-process levels. If a system must rotate between products because of the limited availability of tooling, then many small batches may be preferable to fewer large batches. This is common in computer numerical control (CNC) equipment where tooling racks are product specific. This is even more evident when the variation in process times between products is large.

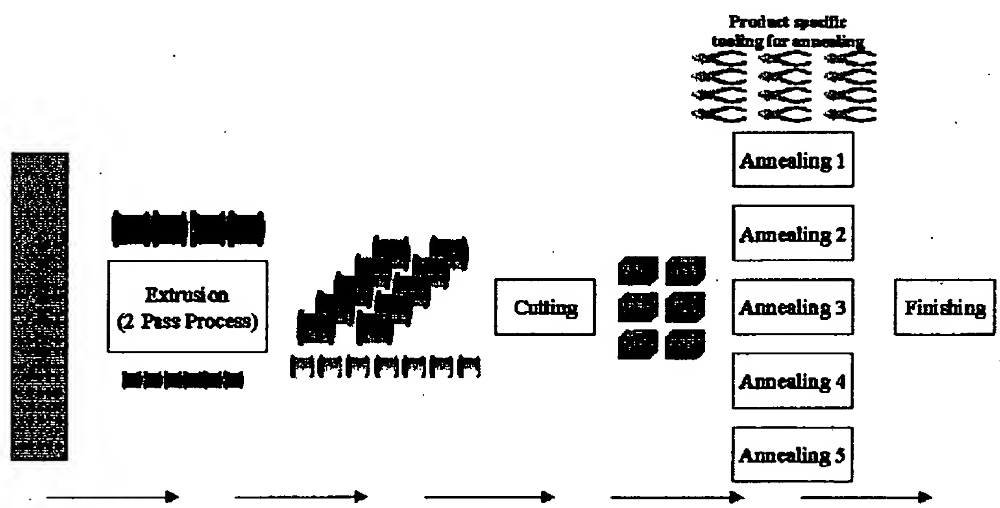
3.3.4 Case Study - FlexFab Inc.

In manufacturing, there is a constant need to balance the trade-off between minimizing work-in-process inventory and maximizing production efficiency. Figure 6 depicts a production process that serves as an excellent example of this trade-off. The process shown is used to manufacture over 600 different SKUs, some of which are high volume items, others specialty goods. Some stages of the production process can significantly benefit from larger productions runs of the same product while others stages are hindered tremendously by the lack of product variety.

At the first stage in the process (extrusion), raw material is converted into an intermediate product in tube form. The tube material is flexible enough to be placed on spools for transporting, protecting, and storing the intermediate product. There are approximately 60 intermediate products of varying size and composition. The spools (small and large), because of their limited availability, act as a type of Kanban to the system. The extrusion process is marred by a significant changeover requirement where changeovers can consume upwards of 50% of the machine's available time. Therefore, to increase the efficiency of the extrusion process, large production runs of the same, or similar, products would be preferable.

The second operation (cutting), is a manual operation by which the intermediate product is cut to product-specific lengths to meet the production needs of the annealing phase. Once again, large production runs of the same material would save time and increase the efficiency of the cutting operation.

Figure 6



However, at the annealing operation, each of the 600+ products requires unique tooling to hold the item in place during the annealing process. Therefore, in order to support large production runs, there would need to be a very large inventory of tools. Due to the capital cost of the tools, tool purchasing is kept to an absolute minimum. To maximize the utilization of the annealing ovens, operators combine a wide variety of parts (each with their own tooling) to make full loads.

Table 5 summarizes the drivers for efficiency in each production step. Notice that the annealing stage's driver is completely opposite to the drivers for extrusion and cutting. Annealing would rather see an extremely large variety of products held in work-in-process. Therefore, in order to minimize work-in-process inventory levels, pressure is placed on extrusion and cutting for small production runs.

Table 5

Operation	Efficiency Driver
Extrusion	Large Production Runs
Cutting	Large Production Runs
Annealing	Large variety of products in work-in-process

Simulation is an excellent tool for investigating a system such as this. The management uses simulation to analyze the following aspects of this system:

- Trade off between large and small batches
- Change-over requirements of the extruder
- Effect of the forecasted order book
- Capital expenditures for tooling
- Resulting inventory levels
- Capital expenditure on spools to support increased inventory
- Staffing requirements

3.4 Adopting Simulation as a Tool

Simulation is now easier than ever to adopt as a tool within any organization. Reduced cost, improved usability, a shallower learning curve, components (reusable objects), templates (pre-built simulations), and the availability of support services all support the growth in simulation's popularity and rate of adoption.

3.4.1 Prerequisite Knowledge

Although simulation is easier than ever, we have identified a number of supporting skills required to undertake successful simulation projects.

- Analytical and logical thinking
- Spreadsheet savvy
- Familiarity with basic statistical concepts
- Basic computer programming skills
- Project management skills

For an excellent review of the ideal skills set, please see Rohrer and Banks' article "Required Skills of a Simulation Analyst".

3.4.2 Software

There are more simulation vendors than ever before, with a wide rage of solutions available. Table 6 contains a partial list of software vendors with leading edge products ranging in price from several hundred to tens of thousands of dollars. For a survey of software solutions, you may wish to consult http://www.lionhrtpub.com/orms.

Table 6

Brooks Automation	CACI Products Company	Delmia Corp.
Flexsim Software Products	Frontstep, Inc	Imagine That
Lanner Group	Micro Analysis and Design	Minuteman Software

Orca Computer	Promodel Corporation	Rockwell Software
SIMUL8 Corp.	Simulation Dynamics	XJ Technologies

3.4.3 Training/Reference Materials

Most software vendors offer training and consulting services to support their products. You will also find a number of professional service companies who specialize in simulation. Many of these companies are independent of the software vendors and support a number of software products. There are a number of annual conferences that attract a wide range of simulation professionals. Two you may wish to attend include: IIE's Simulation Solutions conference (www.simsol.org) or the Winter Simulation Conference (www.wintersim.org)

For a complete list of books and reference materials to support all facets of simulation, you may wish to visit www.NovaSim.com/Bookstore.htm

4 Conclusion

Lean manufacturing initiatives target the reduction of unnecessary inventory within a process or organization. This paper outlined many of the reasons that inventory may be required in a system including buffering random elements and dynamic interaction. Simulation is extremely well-suited as a tool to assist managers in assessing the correct inventory levels necessary to absorb the natural variation within any system.

Biographical Sketch

Jaret Hauge is the co-founder and principal consultant of NovaSim, a simulation services and consulting company headquartered in Bellingham, WA. Before co-founding NovaSim, Jaret headed the technical support, consulting services, and product sales for SIMUL8 while working at Visual Thinking International. He holds a Master of Applied Science in Operations Research from the University of Waterloo and a Bachelor of Commerce degree from the University of Alberta. Jaret's primary focus at NovaSim is in the development of simulation-based decision support applications.

Kerrie Paige is the president and co-founder of NovaSim. After earning a B.S., Summa Cum Laude, from the University of Puget Sound, a M.S. in Applied Mathematics and a Ph.D. in Operations Research from the University of Colorado at Boulder, Kerrie owned a successful consulting company specializing in computer simulation, optimization, and statistical analysis. Now, with over ten years of applied modeling experience, her primary focus is in the development of discrete-event simulation models and the statistical analysis of input and output data.

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